UC DAVIS THERMAL ENERGY STORAGE (TES) TANK OPTIMIZATION INVESTIGATION

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ABSTRACT

Current operation of chillers and the thermal energy storage tank at the University of California, Davis focuses on meeting demand. This report provides an overview of current operation and simple operations recommendations that improve operation efficiency. These operations improvements translate to over $30,000 in savings annually.

INTRODUCTION

The University of California, Davis campus supplies cooling to its building via chilled water through a loop supplied by two central plants on campus. The thermal energy storage (TES) plant consists of 4 ~2000 ton chillers and a ~5M gallon chilled water thermal energy storage tank that supplements chilled water to the loop during peak demand during the summer. The central heating and cooling plant (CHCP) consists of an additional 3 ~2000 ton chillers that are used only during the summertime to meet the base cooling load of the campus. Each chiller is individually operated from the control room at the CHCP through a computer interface.

A chiller cools water through a series of heat exchanges. After chilled water is used in a building, it returns to the chiller. Heat is removed from the water through heat exchange with an internal refrigerant loop. A compressor circulates the internal refrigerant loop and heat is removed through heat exchange with an external condenser loop, which rejects heat to the outside air through a cooling tower. The more heat that is able to be rejected to the outside air through the cooling tower, the lower the temperature of the incoming condenser water. Cooler incoming condenser water can remove more heat from the refrigerant and the chiller operates more efficiently. The amount of heat rejected to the air by the cooling tower is related to the outside air temperature; while not the only factor, the cooler the outside air, the more heat it is able to accept from the cooling tower heat rejection. Therefore, cooler outside air temperatures generally result in more efficient chiller operation. Actual data supports the relationship between chiller efficiency and incoming condenser water temperature (Figure 1).

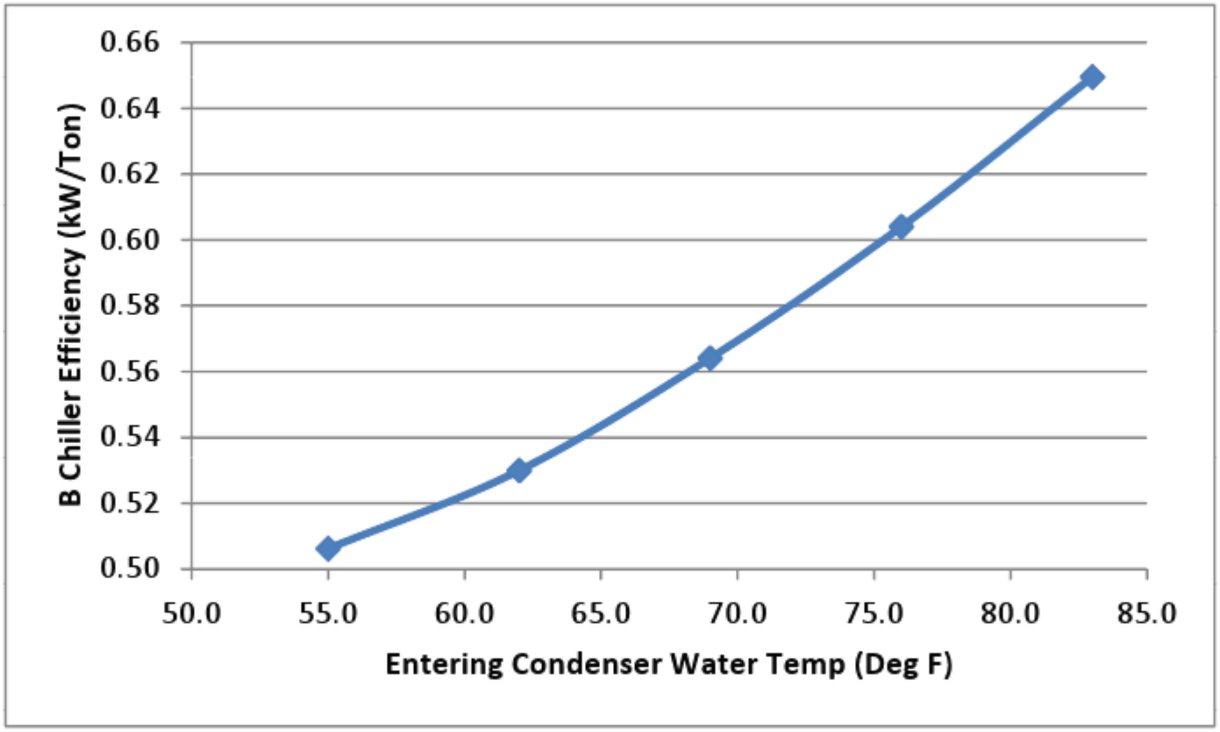

Figure 1: B Chiller Efficiency Curve

METHODOLOGY

To understand current operation, it was necessary to perform a complete investigation of the operators. The chillers and TES tank are operated continuously and three shifts of operators are responsible for operation and maintenance. Each of the three shifts, as well as the daytime manager, was interviewed to gain an understanding of the operation and how each shift operates differently.

In addition to the knowledge gained through the interview, years of historical data was available for dozens of parameters. These parameters included charge state of the TES tank, flow rates, power consumption, water and air temperatures, campus cooling load and many more. These data were analyzed to confirm operator statements and also to identify problem areas and make suggest improvements.

INTERVIEWS

Operators at the CHCP and TES plants provide all the heating and cooling to campus. Their main duty is the meet the demand without having to think about efficiencies or optimize performance. The plant operates 24 hours a day and operators are divided into three shifts: day-shift, swing-shift, and graveyard-shift. Operators have set shifts - meaning if they select to work during swing-shift, they will remain there; however, their roles change day-to-day. One operator indicated that he only act as an operator once a week and as a maintenance personnel at other times. Operators and maintenance workers go hand-in-hand because turning on chillers require at least two people on the shift. Turning on a chiller only takes the click of a button, but for security measures, one maintenance person needs to be available in case something doesn't work because the operator cannot leave the control room unattended. Interview questions and responses can be found in Appendix A.

Day-shift

Operators in the day-shift would like to start the day off with a full tank because the campus demand starts to increase during their shift. At the beginning of their shift, most of the chillers are already turned off with an exception during summer. When the demand is high during the summer, some chillers run for 24 hours. They usually like to leave the tank at around 40-50% for the next shift, but can vary based on the usage. In the summertime, they turn on the chillers at 3pm to keep the tank at a reasonable charge.

Swing-shift

Operators from this shift think this is probably the easiest shift out of the three. During the summer, all of the chillers are already on at the beginning of their shift and they usually leave them on the entire time. However, during the winter, they are responsible to turn on the chillers at 9pm and start charging the tank. They start charging at 9pm to give the operators in the graveyard shift less pressure to completely charge the tank by 8am.

Graveyard-shift

Before talking to the operators, it was assumed that graveyard-shift would be responsible for charging the tank, but they actually do not decide when to start charging the tank. All year long during the summer and winter, all the chillers are already running and tank is already charging at the beginning of their shift. At the time of the interview, the tank was at 75% at midnight. Certainly this takes some pressure off their shoulders to have the tank ready by 8am.

After interviewing with the operators, it seems like some things certainly can be changed in terms of operations to better utilize the tank and chillers. For example, having the tank 75% at midnight doesn't sound very efficient when charging is most efficient during graveyard shift. Following the interviews, historical data from 2011-2012 fiscal year was studied.

Results

As operations vary day-by-day depending on campus demand and outside air temperature, the biggest difference in operation is between summer and winter months. Because the campus cooling demand is high during the summer, both the CHCP and TES plants are needed to meet the demand. On the other hand, the TES plant has enough cooling capacity to meet the demand during the winter. Historical data from July 2011 and December 2011 are used to get a general sense of summer and winter operation.

SUMMER

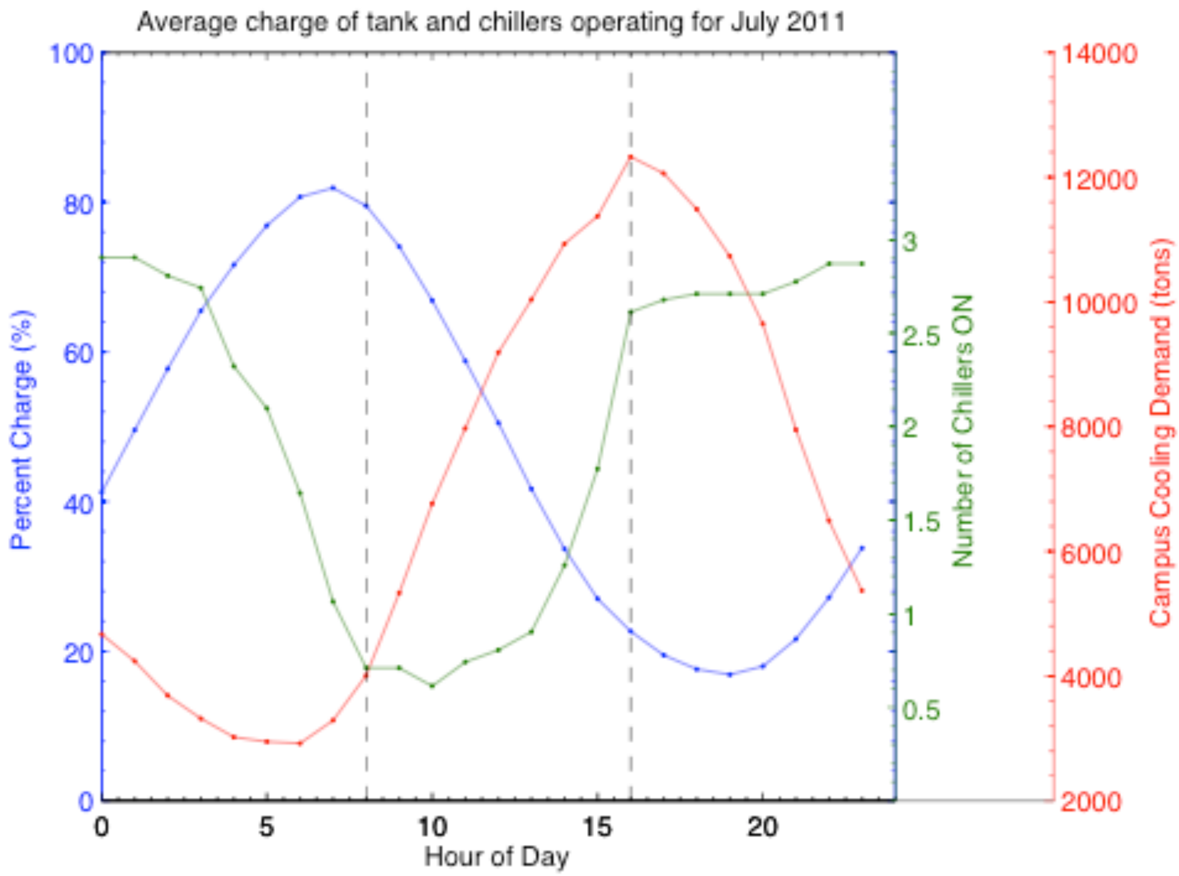

Figure 2 – Average charge of thermal energy storage tank and number of chillers operating in a day for July 2011. Average outside air temperature (Hi/Lo): 96.9/63.5 deg F.

The average state of charge of the TES tank, number of chillers operating, and total campus cooling demand for a day are shown in Figure 2. This represents the operation of the tank during the summer when the outside air temperature and cooling demand are high. As can be seen, the operation of the chillers is fairly consistent with the information provided from the operators during the interviews. During the dayshift, the operators usually leave one chiller on to meet some of the demand. By 3-4pm, all three chillers are turned on to provide cooling to campus because of the peak demand and they remain on until the tank is fully charged. From the plot, the tank starts charging at around 9pm and completes in a time period between 4-8am. This accounts for the downward slope of the number of chillers operating during the graveyard shift. This means that with current operations, operators are not utilizing the entire graveyard shift to charge the tank when chillers are most efficient.

WINTER

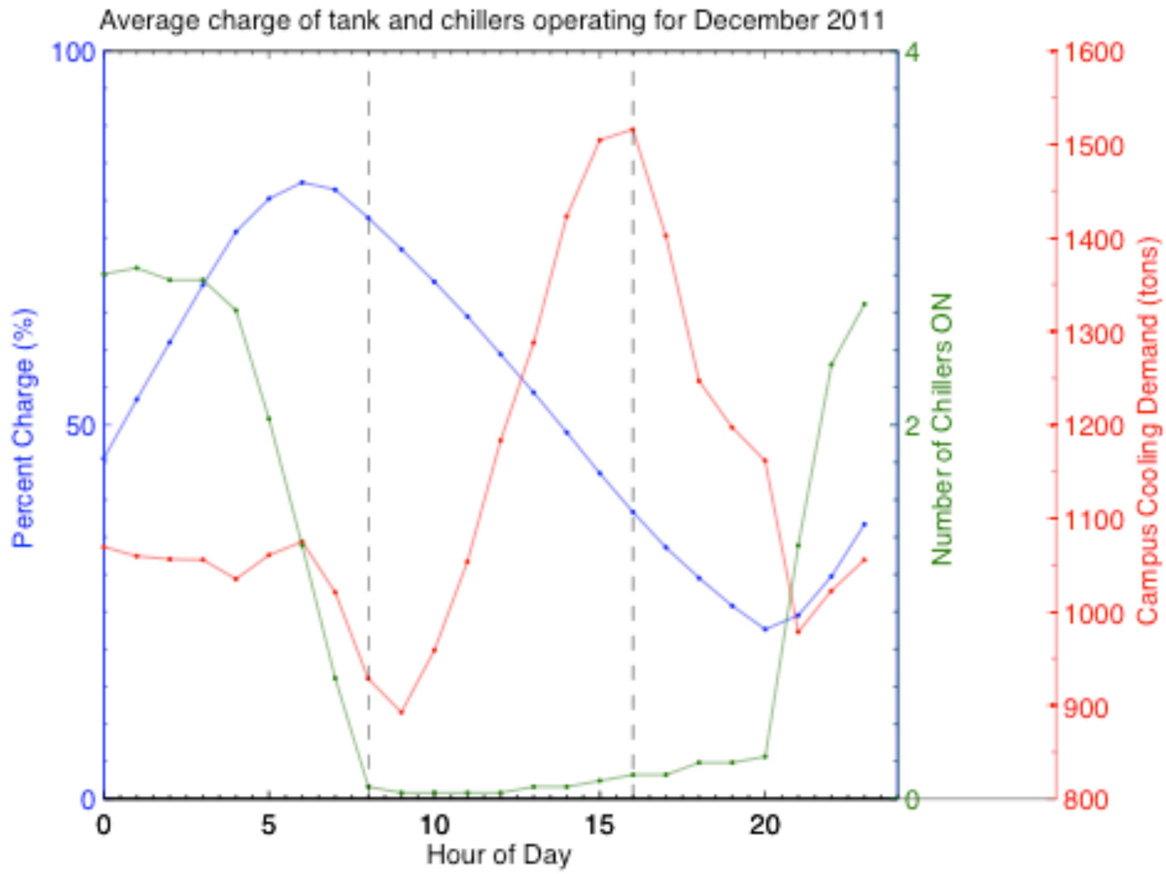

Figure 3 – Average charge of thermal energy storage tank and number of chillers operating in a day for December 2011. Average outside air temperature (Hi/Lo): 59.7/43.4 deg F.

Winter operations are also very consistent with the information provided from the operators. As can be seen in Figure 3, the TES tank has enough capacity to provide all of the campus demand during the day without running any chillers. Although the demand peaks at the same time during the winter and summer at 5pm, the demand during the winter is only a little more than 10% of the demand during the summer. Regardless of the state of charge, chillers turn on at 9pm to start charging the tank. Similar to during the summer, the tank is completely charged at around 4-8am.

SUGGESTIONS

SUMMER

A simple and conservative way to run chillers more efficiently without any big changes to current operations is to simply delay the charge time. Currently, all three chillers are turned on start at 3pm to provide cooling to campus, but remains on through the graveyard shift until the tank is completely charged. According to Figure 2, the tank starts charging around 9pm and completes around 4-8am. With the outside air temperature being the lowest during the graveyard shift, delaying the charge time until 11pm will utilize the time during graveyard shift to charge the tank (Table 1). In some cases where the tank will not be fully charged by 8am, leaving the chillers on to complete the charge after 8am is feasible.

Table 1 – Average temperature of each hour in a day for July 2011

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Temp (°F)	70.3	68.3	66.8	65.2	64.7	64.1	63.7	64.7	73.0	77.4	78.1	81.4
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Temp (°F)	84.7	87.8	90.5	92.4	93.5	94.0	96.6	93.8	84.2	78.7	74.6	72.0

In order to operate chillers more efficiently, chillers need to run when the outside air temperature is low. As can be seen in Figure 2, all three chillers start operating at 3pm when the outside air temperature is the highest; therefore, running chillers at another time to prevent having to operate during the hottest time of the day will experience the most savings. With current operations, the chillers cannot be simply turned off during this time because of the high campus demand. In order to have enough cooling capacity in the tank during this time, the tank will need to be fully charged later in the day. To do so, more chillers will need to be running in the morning to provide the campus load and keep the tank charged. By noon, normal summer operation with running only one chiller can be resumed. That way, not only is the tank providing cooling to campus, but at an optimal time of the day.

WINTER

Current winter operations seem to make use of the TES tank well because of lower demand. On average, the tank has enough capacity to provide all of campus' cooling without having to run chillers in the daytime. However, one area that can be improved is the charge time. Again, the tank starts charging at around 9pm, but would be ideal to use the entire graveyard shift for charging. Instead of turning on chillers at 9pm to start charging the tank, shifting the time to midnight will improve chiller efficiencies. From Table 2, the outside air temperature is slightly lower in the early morning than at 9pm. Again, if the tank is not fully charged by 8am, leaving the chillers on for one or two extra hours would still be more efficient than current operations.

Table 2 – Average temperature of each hour in a day for December 2011

Hour	0	1	2	3	4	5	6	7	8	9	10	11
Temp (°F)	48.2	47.7	47.3	46.6	45.7	45.0	44.7	44.8	46.4	49.2	51.9	54.4
Hour	12	13	14	15	16	17	18	19	20	21	22	23
Temp (°F)	56.5	58.1	58.7	58.7	57.5	54.8	53.4	52.5	51.7	51.1	49.7	48.8

ENERGY ANALYSIS

During summer time, according to previous analysis, turning chillers on at lower outside temperature will improve the efficiency. Therefore, the proposed chiller operation is shown in

Figure 4. We suggest turning the chillers on 3 hours later than current operation. Due to this shift, the percent charge of TES will change consistently.

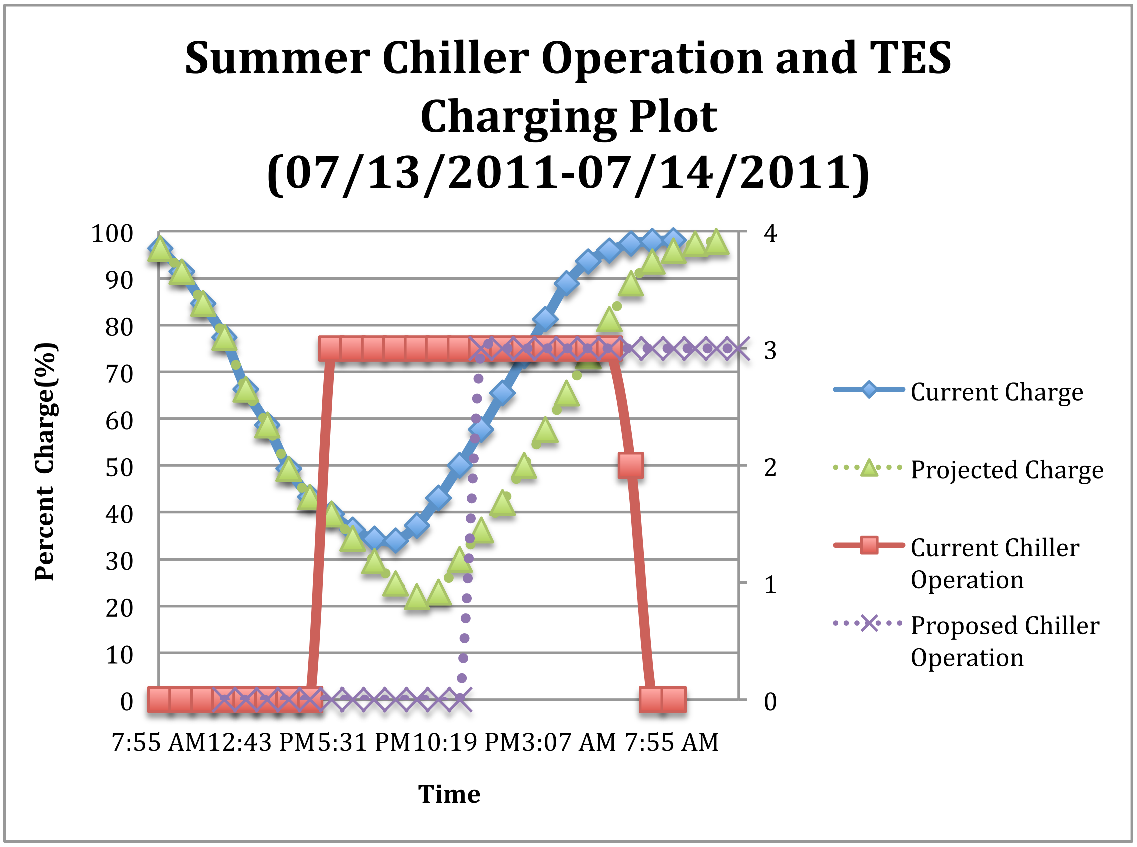

Figure 4 - Summer Chiller Operation and TES Charging

During wintertime, current operation of the TES is well compared with summer operation. But still there is a small temperature difference between 9pm to 12 am and 8 am to 11 am, so we can make an improvement by shifting the operation by 3 hours.

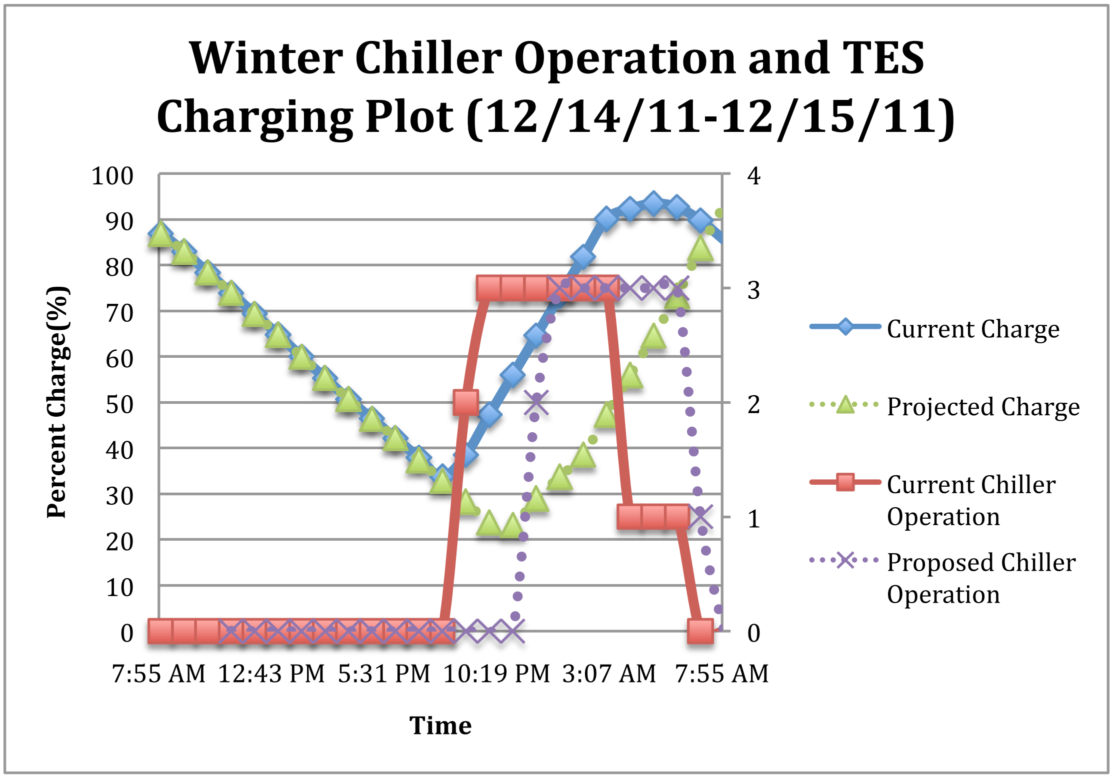

Figure 5 - Winter Chiller Operation and TES Charging

Energy analysis is displayed in Table 3. The temperature difference is the average outside temperature difference of each month due to the 3 hour operation shift (3pm to 6pm and 5am to 8am in summer, 9pm to 12am and 8am to 11am in winter). The efficiency difference shows the improvement due to this temperature difference. Since on average, three chillers are used to charge the TES tank and each has a 2000 ton capacity, the total monthly energy savings is calculated using this equation:

Energy Savings = Efficiency difference (kW/ton)* 3(chillers) * 2000 (ton/chiller) *3 (hours) * days

Assuming an electricity cost of 8 cents/kWh, the total savings of each month are shown in Table 3.

Table 3 - Energy analysis

Month	Temp Difference	Efficiency Difference (kW/ton)	Energy Savings (kWh)	Savings ($)
Jan	3.34	0.02	11,160	$892.8
Feb	3.29	0.02	10,440	$835.2
Mar	1.76	0.01	5,580	$446.4
Apr	6.71	0.03	16,200	$1296
May	14.57	0.1	55,800	$4464
Jun	16.03	0.1	54,000	$4320
July	16.66	0.1	55,800	$4464

Aug	20.63	0.11	61,380	$4910.4
Sep	18.80	0.11	59,400	$4752
Oct	13.35	0.09	50,220	$4017.6
Nov	3.54	0.02	10,800	$864
Dec	4.23	0.02	11,160	$892.8
Sum			401,940	$32,155.2

Based on all of the assumptions above, we can calculate the annually energy savings is 401,940 kWh and savings is $32,155.2.

SUMMARY

We can optimize the use of TES tank by running the chillers at lower outside air temperature. At lower outside air temperature, chillers perform more efficiently.

In current summer operation, three chillers are turned on at 3pm when the outside air temperature is the highest during the day. The reason is because of the high cooling demand. To optimize the operation, we suggest shift current operation by 3 hours and running more chillers in the morning at a lower outside air temperature to charge the tank. Then keep one chiller on and use this chiller and the TES tank to provide the high cooling demand of campus in the afternoon.

In current winter operation, the TES tank has enough capacity to supply the whole campus because of lower demand. In the winter, the morning outside air temperature is lower than 9 pm to 12 am. So we suggest start charging the tank at midnight. In this way, the lower outside temperature will improve the chiller efficiency.

The energy analysis shows that annual energy savings is 401,940 kWh, translating to a savings of $32,155 per year.

APPENDIX A

Operator: Manager
Shift: n/a

How often do you need to turn on chillers in the daytime?
(It) depends on the demand. Chillers can be running 24 hours during hot days and none in winter.

What indicates the need to turn on more chillers?
Operators would try to look at temperature and humidity a day ahead, but usually look at the control system. There is an estimated value of the number of hours left in the TES.

Do all the chillers behave the same way? How are their efficiencies?
All chillers have a 20-year lifetime and they roughly behave the same way.

Do you operate differently during the summer compared to winter? hot day or cold day?
Yes, we play around during the shoulder season and leave chillers on-line during Indian season.

Since there are multiple chillers (parallel/series), how do you determine which ones to use?
(It) doesn't matter which one because they all behave roughly the same. We rarely run chiller in series because of lower efficiencies, but have the option to do so.

Do you have any thoughts or ideas on how to operate differently that might increase the performance of the TES system?
Many factors play into performance such as the building side and operator's choice. There is certainly room for improvement, but I think we're pretty close.

Operator: Oscar
Shift: Day
Interviewers: Matt and Danny

What are some of the responsibilities for this shift?
Try not to deplete the tank, but main goal is the meet the demand. I usually try to leave around 40-50% for the next shift. 20% would be pushing it.

What indicates the need to turn on more chillers?
Usually when there is around 0.5 hours left to discharge.

Do you operate differently during the summer compared to winter? hot day or cold day?
During the winter, we turn off all the chillers at CHCP and only use TES.

What are some of the decisions you have to make?
The percent charge of the tank is really important. On hot days where the demand is high, we need to decide whether or not to turn on chillers in the daytime to save a portion of the tank just in case something happens.

Operator: Jess
Shift: Swing
Interviewers: Danny and Mianfeng

Do you look at temperature forecast before your shift?
Yes, so I have an idea of how to operate.

How much of the tank do you usually leave for graveyard shift?
I start charging the tank at 9pm and let the graveyard shift decide what to do. On hot days like to day, chillers are already on when I came in so I just leave it on and decide if anything needs to change at around 10pm.

The day shift left you with 40% and by the time of your shift all three chillers on and the tank can last 5 more hours. Why do you leave the chillers on?
One reason why the chillers are on before my shift is because I am the only one here today. In order to turn on chillers, there needs to be at least one other person, usually maintenance guy, in the plant just in case the valves don't work. Then someone will need to go fix it.

What indicates the need to turn on more chillers?
(It) depends on the demand and the number of hours left in the tank.

What is the first thing you do or check for in your shift?
I check the boilers and then check it again every two hours.

Operator: Jason
Shift: Graveyard
Interviewers: Mianfeng and Matt

How often do you need to turn on chillers in the night?
The chillers normally are turned on in previous shift. But if it is a hot day, I will turn more chillers on in case of high cooling demand.

How many chillers are normally used to charge the TES plant during night?
Normally 2 or 3, but the most important thing is to forecast the hot days.

When charging the TES plant, do you use more chillers to shorten the charging time or use less chillers with a longer charging time?
I charge the tank as fast as I can. Use more chillers to shorten the charging time.

What indicates the need to turn more chillers on?
Again, forecast the weather. If I think the weather is hot, I will keep the chillers on during the morning two more hours. This can avoid TES used up by 3pm and turns the chiller back on. But the morning shift always turn of the chillers in the morning and turn it back on when it's too hot.

Do you operate differently during the summer compared to winter? Hot day and cold day?
In the winter, because the demand is low, so we might charge the tank every 3 days. The Tank can supply the whole campus demand for 3 days.

Since there were multiple chillers (parallel/series), how do you determine which ones to use?
I actually am told to run 3&4 for a while. Chiller 1 and 2 are different with 3 and 4. 1 and 2 are older. 3 and 4 are connected. They can operate in series or parallel. Shut down 3 or 4 will shut down both and need turn one back on.

Do you have any thoughts or ideas on how to operate differently that might increase the performance of the TES system?
A: In the morning, maybe need chillers keep running to avoid turning it back on because of TES drained in the afternoon.